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IMPLICIT ESTIMATES OF NATURAL, TREND, AND CYCLICAL COMPONENTS OF REAL GNP

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Implicit Estimates of Natural, Trend, and Cyclical Components of Real GNP

ABSTRACT

Estimates of the natural or full employment level of real GNP have usually been obtained by statistical detrending procedures which assume independence between trend and cycle. This paper presents an alternative approach which says that the natural level should be measured in the context of a macro model. If the quantity equation holds with money exogenous and if the price level is sticky, then observed real GNP will reflect both nominal shocks, which are observed, and real shocks, which are unobserved shifts in the natural level. The path of the natural level is then implicit in the data given the model. Calculated paths of the natural level of U.S. real GNP and the resulting business cycle are presented.

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1. Introduction

A series of recent papers has renewed interest in an old problem in economic measurement: how should we decompose aggregate output into its "natural" or "full employment" level and the "business cycle" which is the deviation of actual output from the natural level? One motivation for asking the question is that we claim to have some theories of the business cycle which may suggest policies that could be taken to reduce them. Another motivation is that we would like to test these theories and we need to identify the two components empirically in order to do so. The traditional solution to the problem has been to assume that the natural level follows an exponential function with a constant growth rate so the cyclical component is revealed as the residuals in the regression of the log of output on time. The idea, apparently, is that long term growth must be due to growth in the natural level and since regression on time removes growth from the data it corresponds to the decomposition we seek. While the first part is true by assumption, the second need not follow. The natural level may be subject to transitory disturbances, for example weather, which would then be included in the business cycle. More fundamentally, the natural level may itself be a stochastic process which grows because it is nonstationary rather than because it depends deterministically on time. In an earlier paper, Charles I. Plosser and I pointed out that the presence of a deterministic time trend is a testable hypothesis which enjoys little support from the data. If the deterministic trend hypothesis is wrong, then regression detrending will confound business cycle movements with stochastic variation in the natural level.

Harvey (1985) has suggested that the decomposition problem be cast in the state space framework with output consisting of a stationary cycle plus a drifting random walk which accounts for long term growth. The two components are assumed to be statistically independent in order to identify the state space model. The Kalman filter is used to calculate estimates of the random walk and cycle components. Watson (1986) and Clark (1986) have applied the state space model to post-war U.S. quarterly data. An alternative univariate (using only data on the variable itself) detrending method is that suggested by Stephen Beveridge and myself (1981) in which the trend is defined as the long range forecast obtained from an ARIMA model. The identifying assumption of independence between the components in the state space model would seem to be crucial for the picture that emerges since both Watson and Clark find that it implies far greater variation in the cycle component and far less in the trend component than does the Beveridge/Nelson definition which does not impose independence.

One of the objectives of this paper is to suggest that the assumption of statistical independence between the business cycle and the natural level may be an economically inappropriate one to impose a priori. If it is inappropriate, then resulting estimates of trend and cycle will not correspond to the natural level and the deviations from it that we would like to measure. Sir John Hicks (1965) made the point very clearly when he wrote:

> "...The distinction between trend and fluctuation is a statistical distinction; it is an unquestionably useful device for statistical summarizing. Since economic theory is to be applied to statistics, which are arranged in this manner, a corresponding arrangement of theory will (no doubt) often be convenient. But this gives us no reason to suppose that there is anything corresponding to it on the economic side which is at all fundamental. We have no right to conclude, from the mere existence of the statistical device, that the economic forces making for trend and for fluctuation are any different, so that they have to be analyzed in different ways."

The approach to measurement of the natural and cyclical components proposed in this paper departs from past efforts in two fundamental respects. First, it abandons the assumption of independence between trend and cycle, allowing instead for interaction between them. Second, it is based on a model of fluctuations in output where nominal and real shocks both play a role. As a starting point I take for granted that actual output at time t, say Q_t in logs, is a function of the sequence of nominal shocks as well as the path of the natural level of output. The latter may be thought of as indexing the production possibilities frontier facing the economy and reflects the growth of the stocks of capital, labor and technology as well as real shocks which may be in part transitory (the weather) and in part permanent. In general there is a relation of the form

$$(1) \qquad Q_t = Q(..\underline{Y}_{t-1}, \underline{Y}_t; .., QN_{t-1}, QN_t)$$

where $\underline{Y}$ is a vector of nominal variables and QN denotes the natural level of output.

The general strategy proposed in this paper is to use the relationship between observed Q and observed $\underline{Y}$ to infer the unobserved value of QN. To make this operational of course we need a particular model which specifies the relevant variables. The identifying restriction in this approach is independence between observed variables (which might potentially include some components of QN) and the unobserved components of QN which we wish to infer. A simplifying assumption I make in this paper is that nominal shocks are summarized by nominal GNP, denoted Y, as in the empirical models used by Lucas (1973) and Gordon (1982) so that equation (1) becomes

$$(2) \qquad Q_t = Q(.., Y_{t-1}, Y_t; .., QN_{t-1}, QN_t).$$

The role of equation (2) then is to divide a given exogenous change in nominal spending between changes in output and the price level since the three are linked by the identity Y = Q + P, where P is the log of the price deflator. This recursive structure relating income to output and prices is a characteristic of monetary models in which exogenous movements in monetary aggregates determine nominal income through a money demand function. Some evidence that quarterly GNP data are not seriously at odds with the recursive structure assumption is presented in an earlier paper (Nelson, 1979), and Fama (1981) has demonstrated its consistency with the aversion that the stock market shows to inflation. Lagged adjustment of output and prices to a nominal shock is a property of both sticky price models and models in which prices are flexible but information available to individual agents is incomplete. Stickiness in prices has been a mainstay of macroeconomic theory at least since Hume (1752) and recently has gotten a more rigorous foundation in the literature based on contracting theory. Section 2 of the paper investigates a simple dynamic model suggested by partial adjustment of prices, Section 3 presents the implied natural and trend components of real GNP, Section 4 studies the resulting cyclical component, Section 5 compares these results with alternative methods, and Section 6 offers some conclusions and suggestions for further research.

2. An Empirical Price Adjustment Model

To implement equation (2) empirically I investigate the distributed lag function relating real GNP to nominal GNP using post-war quarterly U.S. data (1947:1 - 1985:4). The history of the natural level of real GNP is implicit in the residuals of this model. Since all of these variables are nonstationary I work with first differences denoted by lower case letters. My expectation was that the long run multiplier in this relationship would be close to zero since an exogenous increase in the growth rate of nominal spending should have little, if any, permanent impact on the growth rate of real GNP or, equivalently, nominal shocks should be ultimately absorbed in the price level. My prior work on the dynamics of inflation for the 1954-1970 period (Nelson, 1979) suggests that the distributed lag will be a simple one with geometric decay of the lag coefficients. I therefore fitted the transfer function (distributed lag model)

$$(3) \qquad q_t = \frac{\omega_0 - \omega_1 L}{1 - \delta L} \quad y_t + c + e_t$$

which implies an impact multiplier of ω_0 and allows for geometric decay at rate δ after a second period effect of $(\delta\omega_0 - \omega_1)$. The long run multiplier effect of y on q (the gain of the transfer function) is given by $(\omega_0 - \omega_1)/(1-\delta)$ so I expected ω_0 and ω_1 to be approximately equal. Least square parameter estimates using the PDQ program TRAN/EST yielded

$$(4) \qquad q_t = \frac{.74 - .75L}{1 - .92L} \quad y_t + .01 + e_t; \ \text{R-sq} = .76$$

which implies a small negative point estimate for the gain and a rather slow rate of decay, both of which are consistent with the results for 1954-1970 period I reported earlier. What is apparent, though, in this longer time period is a persistence in residual autocorrelation which starts at .44 at lag one and declines slowly, suggesting that the residuals behave like an ARMA(1,1) in which case we would have $(1-\phi L)e_t = (1-\tau L)u_t$ where u denotes white noise. Reestimating with that specification, I obtained

$$(5) \qquad q_t = \frac{.75 - .76L}{1 - .94L} y_t + .009 + \frac{1 - 50L}{1 -.83L} u_t$$

$$R^2 = .82;\ F(5,147) = 133.6;\ \sigma_u = .0048;$$

$$Q(12) = 16.98.$$

Remaining residual autocorrelation is not suggestive of a more complex ARMA scheme, nor do cross-correlations between the residuals and the independent variable suggest misspecification of the transfer function. While the point estimate of the gain is negative (-0.04), it is not significant (the difference between estimated ω_0 and ω_1 being a fraction of one standard error).

The two denominator parameters δ and ϕ are both within one standard error of 0.9, indeed the difference between them is not significant. If we take δ and ϕ to be the same parameter we can multiply through by a common factor $(1-\rho L)$, where ρ is about 0.9, thereby putting it in ARMAX form. After estimating the ARMAX model using micro-TSP we have

$$(6) \qquad q_t = \underset{(.09)}{.90}\, q_{t-1} + (\underset{(.03)}{.76} - \underset{(.07)}{.73}L)y_t + (1-\underset{(.12)}{.59}L)u_t$$

$$R^2 = .82;\ F = 165.0;\ \sigma_u = .0049$$

which effectively gives the same fit to the data as did the unconstrained transfer function.

It is readily shown that an equation of this form would be implied by partial adjustment of the price level in response to shifts in Y and QN. If the price level were completely flexible then actual Q would always be equal to QN and the price level would be $PN_t \equiv Y_t - QN_t$ where PN may be thought of as the natural level of the price index. If the price level is not completely flexible but rather the actual price level at time t depends also on past actual price levels then the simplest specification is

$$(7) \qquad P_t = \lambda P_{t-1} + (1-\lambda) PN_t; \; 0 < \lambda < 1.$$

Replacing P by its equivalent (Y-Q) and PN by (Y-QN), taking first differences, and solving for q_t we have

$$(8) \qquad q_t = \frac{\lambda-\lambda L}{1-\lambda L} \bullet y_t + \frac{(1-\lambda)}{1-\lambda L} \bullet qn_t$$

where qn denotes the first difference of the log of QN. Equation (8) describes the lagged adjustment of output to changes in nominal spending and the natural level of output. In this heuristic model there is one parameter, l, which corresponds to parameters δ and ϕ of the empirical model (5). It also corresponds to the numerator parameters ω which take on somewhat smaller values empirically than do the denominator parameters. This difference, however, seems to be related to sample period since if we drop the noisier early years and estimate the model for 1954:1 - 1985:4 the numerator parameter values jump to .84 while δ and ϕ remain near .9. A value of around .9 for λ is roughly consistent with the overlapping contracts interpretation of price level adjustment if the U.S. economy is characterized by three year contracts, one twelfth of which adjust each calendar quarter. But there is no need to put too fine a point on it. The objective here is to obtain a simple characterization of the dynamics of nominal and real GNP in order to see what such a model would imply about the behavior of the natural level component of real GNP.

3. The Implied Behavior of the Natural Rate of Output

The next step is to infer the behavior of the natural level of output, QN, from the empirical model given by (5) and (6) by interpreting its parameters in the context of the partial adjustment model given by (8). We associate the error process of equations (5) and (6) with the corresponding term of equation (8) involving qn. The equivalence is

$$(9) \qquad \frac{(1-\lambda)}{(1-\lambda L)} qn_t = \frac{(1-\theta L)}{(1-\lambda L)} u_t + c$$

which implies the relation

$$(10) \qquad qn_t = \frac{(1-\theta L)}{(1-\lambda)} u_t + c'$$

or

$$(11) \qquad qn_t = u_t' - \theta u_{t-1}' + c'$$

$$u_t' = u_t/(1-\lambda).$$

This representation of the natural rate is a first order moving average process in first differences qn where the innovations u_t' are the innovations in the transfer function scaled by the factor $1/(1-\lambda) \approx 10$. The standard deviation of qn (the quarterly growth in QN) is therefore about .05 compared with .01 for the sample standard deviation of actual output growth q, where the scale of these numbers is such that .10 would be 10% over a calendar quarter. But a substantial portion of the variation in qn is transitory. This is not the contradiction in terms that it may seem. Note that the IMA(1,1) structure of QN is consistent with its being composed of a random walk with drift, denoted QT, with innovation v plus a transitory random part, denoted w (for weather). The first difference of QN then has the representation $qn_t = v_t + \Delta w_t$. The autocovariances of qn give two equations in two unknowns:

$$\text{var}(qn) = \text{var}(v) + 2\,\text{var}(w) \tag{12}$$

$$\text{cov}(qn_t, qn_{t-1}) = -\,\text{var}(w).$$

Using values of the moments implied by the empirical model the implied standard deviations of the various components of the growth rate q are then

$$\begin{aligned} \sigma_q &= .01 \\ \sigma_{qn} &= .05 \\ \sigma_v &= .05 \\ \sigma_w &= .03. \end{aligned} \tag{13}$$

The model implies that the innovations v in the stochastic trend underlying the natural level QN are noisier than observed output growth itself, but this of course reflects the smoothing that is implied by the transfer function for q. Rewriting the second term of the model with qn replaced by $(v + \Delta w)$ we have

$$q_t = \text{nominal effects} + \frac{(1-\lambda)}{1-\lambda L}(v_t + \Delta w_t) \tag{14}$$

which says that only about 5 percent of the variance in v shows up in the variance of q. Empirically, we can estimate the history of QT from the history of QN by the usual exponential smoothing formula

$$(15) \qquad QT_t = (1-\theta)\ QN_t + \theta\ QT_{t-1}$$

where θ is the moving average parameter in equation (11) and the QN are understood to be the estimates given the model and the data. This corresponds to the Beveridge/Nelson estimate of the trend component of QN because it is the long range forecast. Equivalently it is the one-sided Kalman filter estimate of the trend component of QN.

Calculation of the natural and trend components is straightforward given the data on q and y, residuals u, and parameter values λ, θ, and c. Figure 1 shows the implied histories of QN and QT along with actual Q using values λ = .9, θ = .5, and c = .009. The time period of the figure is 1970 - 1985 because this allows greater resolution over an interval of particular current interest, but recursive calculation of the components was started in 1947. We see that the major movements in QN and QT correspond to the major oil shocks of 1974, 1980 and (in reverse) 1983. Slowdowns in the growth of the natural rate are apparent in 1970-71, 1973, and in a more prolonged way following 1977. In each case, periods of slow GNP growth ensued. More recently, since 1983, the growth of the natural rate has been rapid, corresponding to more rapid GNP growth and diminishing inflation.

For the entire period 1947-1985 we have the picture shown in Figure 2 where only the trend component is plotted along with actual real GNP. The contrast between the stable price era of the 1950's and the inflation era of the 1970's and the transition in the late 1960's are clear. Also apparent from Figure 2 is that considerable variation in GNP is not due to variation in the natural rate. In particular, the prolonged gaps between the actual and natural levels of GNP from 1951 to 1966 and from 1973 to 1983 stand out. Note that the transfer function model is a way of dividing the variance of GNP growth between the influence of QN and the influence of nominal shocks as summarized by Y. According to equation (4), only about 25 percent of the variance of growth in real GNP is due to variation in the natural rate.

4. The Business Cycle

The deviation of actual GNP from its natural level represents the influence of nominal shocks to the economy as well, in general, as the transitory influence of real shocks. For want of a better term we will join tradition and call this difference between Q and QN the "business cycle" and denote it QC, although there is nothing about the framework of the paper that suggests predictably periodic fluctuations. From the definition of QC and the heuristic model of equation (8) we have

(16) $$QC_t \equiv Q_t - QN_t$$

$$= (\lambda/1-\lambda L)\ y_t + (-\lambda/1-\lambda L)\ qn_t$$

which puts the same lag structure on both sources of variation in Q, although with opposite signs. A positive nominal shock raises GNP relative to the natural rate, while a positive shock to the natural rate raises the natural rate faster than it does output--thereby reducing the cyclical component. In this decomposition there is definitely not independence between the natural rate (or trend) process and the cycle component. They are negatively related.

The stochastic characteristics of the cycle may be derived from equation (16). We start by noting that after multiplying through by the term $(1-\lambda L)$ the QC process has the form

(17) $$QC_t = \lambda\ QC_{t-1} + \lambda y_t - \lambda qn_t.$$

Thus QC is autoregressive with coefficient λ, which suggests strongly autocorrelated (persistent) behavior given values of λ around .9. The last two terms in y and qn can be thought of as the moving average part of the QC process. Recall that qn itself is MA(1) with a coefficient of about 0.5 (following the convention of negative signs in front of MA coefficients). Univariate analysis of y (the quarterly growth rate of nominal GNP) suggests that an AR(1) model is more appropriate than an MA(1) model, but for exploratory purposes let us approximate the former by the latter; noting the coefficient value is about -.4 and denoting its innovations by e we have roughly

(18) $$QC_t = .9\ QC_{t-1} + .9\ (\varepsilon_t + .4\varepsilon_{t-1}) - .9\ (u_t' - .5u_{t-1}')$$

$$\sigma_\varepsilon = .01;\ \sigma_{u'} = .05$$

recalling that u' are the innovations of the QN process. We see that the MA part of the QC process is the sum of two MA(1)'s, one positively autocorrelated and the other negatively. The net result depends then on the relative variances of e and u', and since that of u' is larger, the MA part of QC will display negative autocorrelation. The univariate behavior of Q is then characterized as ARMA(1,1).

To show what this looks like, Figure 3 displays QC over the 1947-1985 period. The long waves in the series reflect the persistence of the effects of y and qn through the AR part of the process, while the chop in the series reflects the negatively autocorrelated MA part of the process. Recall that the MA behavior of qn can be interpreted as being due to the presence of random noise, "the weather," and that is what causes the chop we see in QC. Note that the cycle component of GNP was generally negative until the late 1960's, then persistently positive until the early 1980's, corresponding to the eras of low inflation, rising inflation, and waning inflation in the U.S. economy.

To eliminate some of the noise in QC we can alternatively measure the deviation of actual GNP from the smoothed trend component, that is (Q-QT), since it is QN that is noisy rather than Q. The resulting smoothed cycle is shown in Figure 4. While the historical patterns are of course the same, we get a clearer picture of them. Major dips in the series correspond to some extent to traditional NBER business cycles.

In order to see how nominal and real shocks contributed separately to this overall pattern, the two components of QC from equation (16) are plotted in Figure 5. Nominal influence on the cycle was deflationary, except for the Korean War period, until 1966. It became strongly inflationary in the early 1970's and continued so until 1982. The real influence on the cycle was positive in the late 1940's and negative during the Korean War period, presumably reflecting the ending and later resumption of wartime controls. Large real shocks show up of course in 1974 and to a lesser extent in 1980. Recall that negative real shocks will increase the cycle component. Most interestingly, perhaps, the real contribution to the cycle has been strongly negative since 1982 suggesting that it is this rather than monetary restraint that is largely the source of diminished inflation. Perhaps this is why the monetarists have been consistently wrong in forecasting the return of inflation in recent years. In effect they were only looking at half of the picture and the other half was strongly deflationary.

The nominal and real components of QC make roughly equivalent contributions to its total variation. The standard deviation of QC is .08 while that of the nominal component is .05 and that of the real component is.06 over the 1947-85 period. Since these components are in principle (and by construction) uncorrelated, it follows that each by itself explains, in a regression sense, about half of the variation in QC, with a bit more explanatory power coming from the real component.

5. Comparison With Univariate Trend-Cycle Decomposition

Traditional statistical methods are univariate in that they attempt to infer the paths of trend and cycle components just from the past history of the variable itself. In deterministic trend models the trend line is chosen to minimize cyclical deviations. In the unobserved components model with a random walk stochastic trend suggested by Harvey, the trend component has additional flexibility to track the series and the resulting cyclical deviations are smaller. Clark finds deviations from linear trend in post-war U.S. real GNP of up to 8 percent while the random walk specification for trend reduces this range to about 5 percent. Not surprisingly, the duration of cyclical episodes is also reduced, with the 1965-1974 period being entirely above trend in the linear trend case but being interrupted by the 1970 recession in the random walk case.

Watson and Clark also present estimates of trend using the Beveridge/Nelson method which defines the trend to be the long range forecast of the series based on its autocorrelation structure. It does not impose independence between trend and cycle as does the unobserved components model. For real GNP the Beveridge/Nelson cycle component is small, with a range of only a couple of percent, and variation in real GNP is dominated by variation in trend. This result follows computationally from the fact that quarterly log changes in real GNP are only weakly autocorrelated during the 1947-1985 period with an AR(1) coefficient of .37. Since resulting forecasted changes will be small, the Beveridge/Nelson trend value will differ relatively little from the actual value at any point in time. The unobserved components model produces more variation in the cyclical component by insisting that it move independently of trend.

At the other end of the spectrum in variation and persistence is the cycle implied by the transfer function model. Recall from Figure 4 that the cycle ranges from -.16 to + .18 and makes only one major upswing during the entire post-war period. How is it possible that the real GNP data by itself could contain so little information about the trend that the two become virtually indistinguishable in the Beveridge/Nelson decomposition? The transfer function model suggests why this is so. Note that the model can be rewritten as approximately

$$(19) \qquad (1 - .9L)\, q_t = .75(1-L)y_t + (1-.5L)u_t$$

deleting the constant for clarity. This would seem to imply strong autocorrelation in growth rates q since the coefficient on lagged q is .9. The univariate ARMA representation of q will also, however, involve the ARMA representation of y which is AR(1), as noted before, with coefficient .45. Substituting for y and denoting its innovation again by e we have

$$(20) \qquad (1-.9L)(1-.45L)q_t = .75(1-L)e_t$$
$$+ (1-.95L + .225L^2)u_t.$$

The MA part of the process will be MA(2) but since the variance of e is five times as large as the variance of u it will be dominated by the first order MA in ε which has a unit root. Dividing (20) through by the operator (1-9L) we have approximately

$$(21) \qquad (1-.45L)q_t \approx .75e_t + u_t.$$

The λ parameter that accumulates movements in y and qn into the large and persistent variations we saw in QC has effectively canceled out of the univariate representation. We could hope to detect it only with a very long data record. Therefore q will display relatively weak autocorrelation with a pattern typical of AR(1) behavior.

The additional information that the transfer function gets from y is lost in the univariate model.

6. Conclusions and Suggestions for Further Research

The methodology for decomposition of aggregate output into natural, trend, and cyclical components suggested in this paper turns away from the statistically convenient assumption of independence and proposes instead that the decomposition be model-based. In general, fluctuations in output are attributable to nominal shocks and the path of the natural level of output. The idea is to solve for the implied path of the natural level given the model and data on observable nominal and real variables.

The model used here is a heuristic representation of partial price level adjustment which assumes that the natural rate process proceeds independently of nominal shocks summarized by nominal GNP. Perhaps surprisingly, the model is not strongly at variance with post-war data. The point here though is not to test a theory but to try a different approach to a fundamental problem in economic measurement. The implied natural level of GNP itself separates conveniently into a random walk plus noise; the former being a stochastic trend and the latter purely transitory, perhaps the weather. Variation in the natural level is not independent of the implied business cycle but rather they are negatively correlated, the latter depending directly on the former. The cycle component of GNP is highly autocorrelated and its historical pattern corresponds with the conventional account of the build-up of inflationary pressure in the 1960's and 1970's and the disinflation of the 1980's. The relation of this series to other cyclical indicators, such as the unemployment rate, bears further investigation. The cycle component can be separated into the part due to nominal shocks and the part due to movements in the natural rate. These show quite different patterns although they contribute about equally to total variation. It would appear that the natural rate has played a primary role, for example, in the disinflation of the 1980's.

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Figure 1. GNP: ACTUAL, NATURAL, & TREND

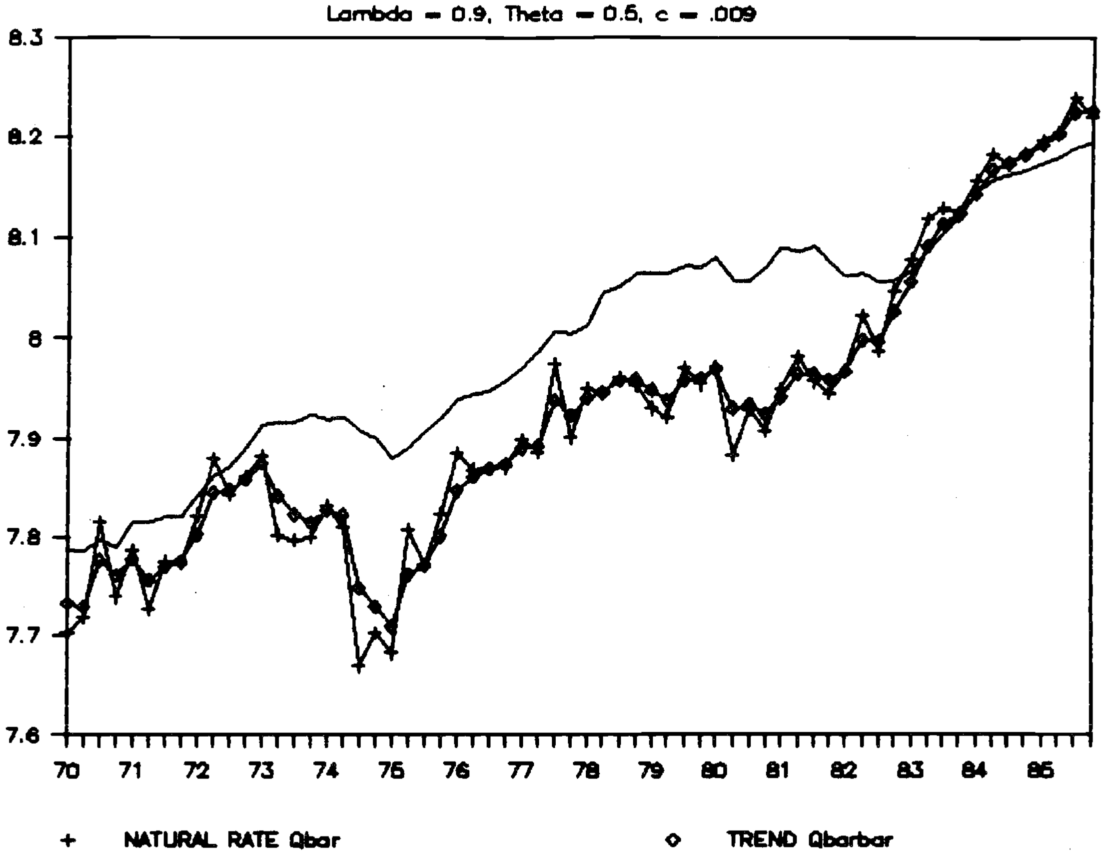

Figure 2. ACTUAL GNP AND TREND (QT)

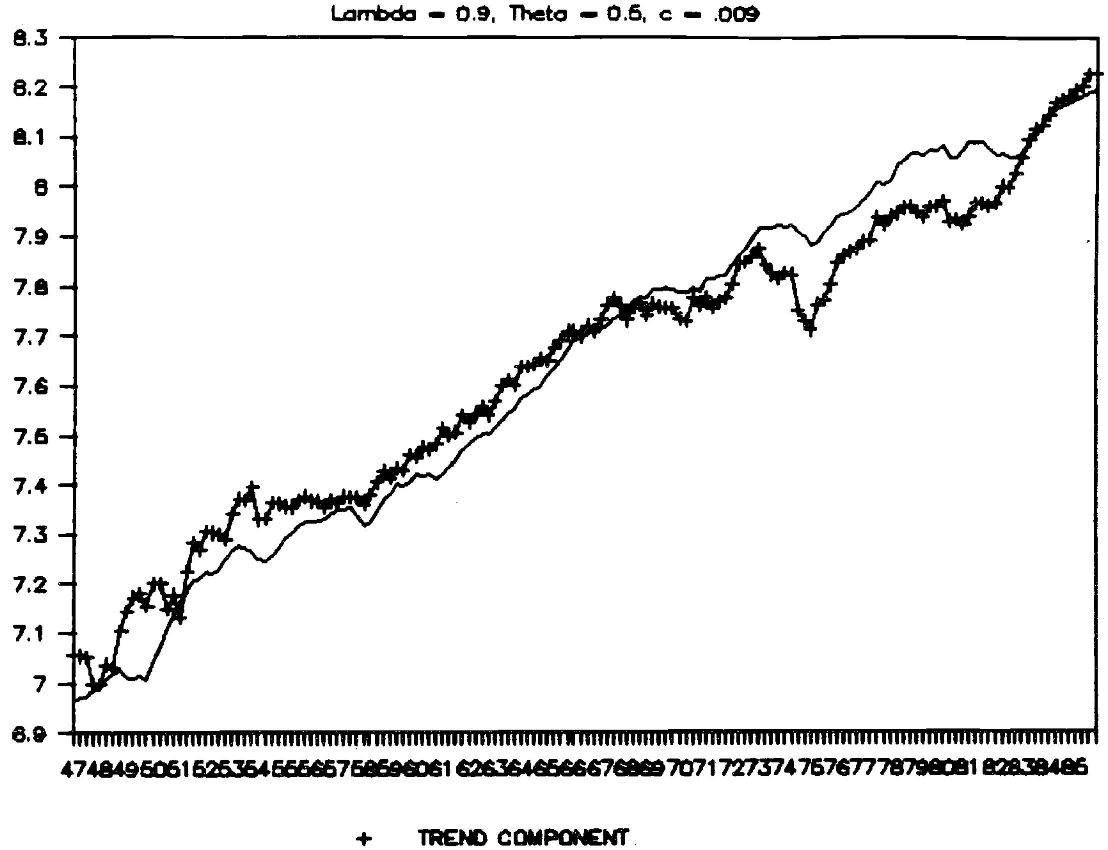

Figure 3. THE BUSINESS CYCLE (QC)

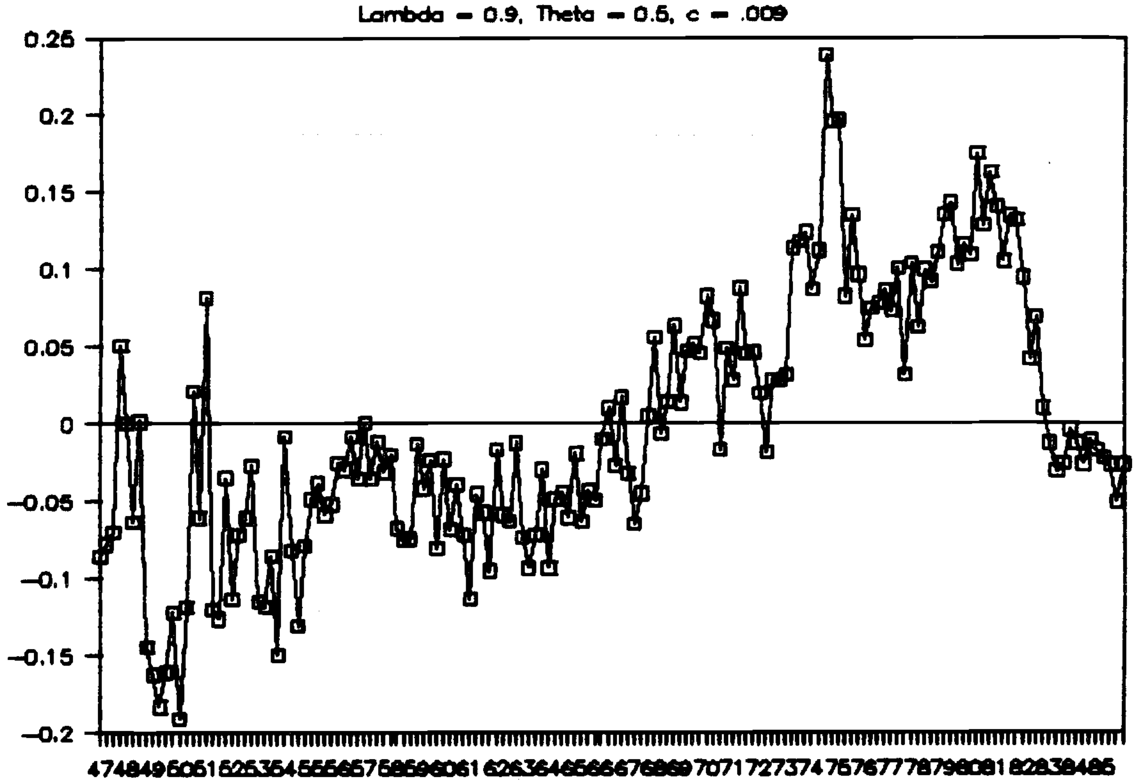

Figure 4. GNP MINUS TREND (Q - QT)

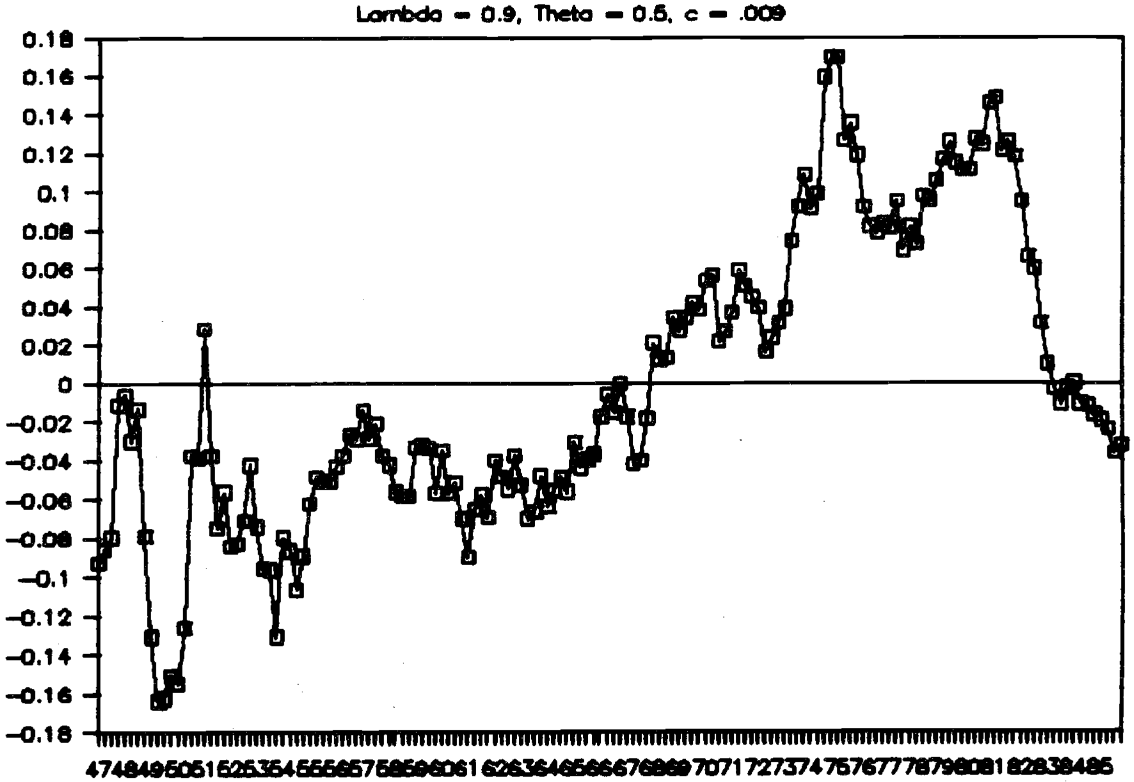

Figure 5. NOMINAL AND REAL PARTS OF THE CYCLE